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PastureBase Ireland: A grassland decision support system and national database

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ABSTRACT

PastureBase Ireland (PBI) is a web-based grassland management application incorporating a dual function of grassland decision support and a centralized national database to collate commercial farm grassland data. This database facilitates the collection and storage of vast quantities of grassland data from grassland farmers. The database spans across ruminant grassland enterprises – dairy, beef and sheep. To help farmers determine appropriate actions around grassland management, we have developed this data informed decision support tool to function at the paddock level. Individual farmers enter data through the completion of regular pasture cover estimations across the farm, allowing the performance of individual paddocks to be evaluated within and across years. To evaluate the PBI system, we compared actual pasture cut experimental data (Etesia cuts) to PBI calculated outputs. We examined three comparisons, comparing PBI outputs to actual pasture cut data, for individual DM yields at defoliation (*Comparison 1*), for cumulative annual DM yields including silage data (*Comparison 2*) and, for cumulative annual DM yields excluding silage data (*Comparison 3*). We found an acceptable accuracy between PBI outputs and pasture cut data when statistically analyzed using relative prediction error and concordance correlation coefficients for the measurement of total annual DM yield (*Comparison 2*), with a relative prediction error of 15.4% and a concordance correlation coefficient of 0.85. We demonstrated an application of the PBI system through analysis of commercial farm data across two years (2014–2015) for 75 commercial farms who actively use the system. The analysis showed there was a significant increase in DM yield from 2014 to 2015. The results indicated a greater variation in pasture growth across paddocks within farms than across farms.

1. Introduction

The ability of Irish farms to grow and utilize grass in an efficient and profitable manner is widely considered to be a major competitive advantage over other ruminant producing countries in terms of low cost animal production (Hurtado-Uria et al., 2013). Research has shown that each 10% increase in the percentage grazed grass as a proportion of the overall diet of a dairy cow reduces the cost of milk production by 2.5c/l (Dillon et al., 2005). This is further emphasized by Finneran et al. (2010) reporting that grazed grass is the most cost effective feed available to all ruminant livestock production systems with a relative cost ratio in 2010 of grazed grass to grass silage and to concentrate of 1:1.8:2.4. The removal of European milk quota restrictions in April 2015 has provided Irish dairy farmers with the opportunity to increase milk output nationally for the first time in a generation. In Ireland, the profitability of such expansion should centre on increasing grass growth and grass utilization at farm level (Shalloo et al., 2011). While significant expansion is expected with the removal of milk quota (Läpple and Hennessy, 2012), such expansion coupled with volatile global milk markets requires that farmers develop sustainable milk production systems focused on technical and financial efficiencies (Kelly et al., 2012). Many studies have highlighted the potential for increased output and productivity from grazed grass through a focus on key components of different aspects of grass based systems. PastureBase Ireland (PBI) has the capability of providing support around grassland management decisions through the provision of decision support tools, and also has the potential to contribute to new research around grassland management.

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Nationally, it is estimated that the average dairy farm utilizes 7.1t of grass DM/ha (Creighton et al., 2011), while more efficient farms are growing and utilizing in excess of 12–14t of grass DM/ha over a 280 day grazing season with stocking rates of over 3 cows/ha (Shalloo et al., 2011). A wide range of factors affect pasture growth at farm level which are outside of a farmer's control including soil type, region, altitude and meteorological conditions. However Shalloo et al. (2011) highlighted grassland management, soil fertility and national reseeding levels as having a strong influence on overall pasture production in Ireland. These are areas of grassland farming that could be vastly improved with the aid of data informed decision making on farm. There are further benefits to be realized from regular pasture measuring and budgeting including greater spring grass supply through improved autumn management, optimum utilization of spring grass, early identification of pasture surpluses and deficits and the achievement of higher performances from pasture based systems (O'Donovan and Dillon, 1999).

The advancement of the internet and in particular the proliferation of smart phones has created opportunities for the development and use of decision support tools that are web enabled (Crowley et al., 2013) such as PBI. The key objective of most of the tools developed is to increase the information available to help the decision making process at farm level (Minchin et al., 2010), while facilitating the collation of large quantities of data in a central data storage platform. The inclusion of the data storage function dramatically increases their functionality, as it enables the development of longer term research based solutions to be established from data collected over a long term period, across a large range of farms. It also provides an automated mechanism to benchmark farms across a whole range of differing criteria from time to region. In the international literature there are examples of decision support tools aimed at improving the decision making process around key aspects of the farm. In the U.S. a goal-oriented decision support tool was developed to determine the best grazing management strategies for California and other Western states (Barry et al., 2005). Australia has developed a range of decision support tools across different aspects of the dairy farm business such as Grazplan (Donnelly et al., 2002). Other grassland management tools include Agrinet which was developed in Ireland and Pasture Coach which is in use in New Zealand.

The objective of this study is to describe, evaluate and demonstrate the utility of a web based grassland decision support tool (PastureBase Ireland (PBI)) for use on grassland farms in Ireland.

2. Materials and methods

2.1. PBI overview

PBI contains a web based PC or smart phone enabled user interface linked to a grassland database which has a dual function of providing real time decision support for farmers and farming practitioners while capturing farm grassland data in the background for benchmarking and research purposes. The system operates with the individual farm paddock as the basic unit of measurement for the farm. The system is operated by the farmer entering the grassland information through the web front end and thus the accuracy and usefulness of the system is determined by the level and accuracy of the data recorded by the user with predefined verification rules programmed into the system. Such verification checks include restrictions on pasture cover estimations (0–3500 kg DM/ha), silage yields (0–10,000 kg DM/ha), residual heights (2.5–9 cm), the time period in which the start and end dates can be chosen for the spring and autumn rotation planners and also rotation lengths in days. All measurements on PBI are described and calculated on a per hectare basis for individual paddocks.

The farmer builds a profile for each paddock through a user friendly intuitive interface by entering information on paddock size, location, soil type, altitude, drainage, etc., which can then be linked to paddock performance over time. Data on paddock characteristics can potentially assist in explaining how individual paddocks perform. This data also allows the farm to be categorized at paddock, farm and regional level for the purpose of benchmarking or as part of ongoing research. The farmer enters weekly pasture cover estimations, from which PBI produces a series of daily and periodic outputs depending on the requirements of the end user (Fig. 1). Daily outputs are used for increasing the precision of daily grassland management decision making. The periodic outputs allow for further analysis of paddock and farm performances over a greater time period.

2.2. Decision support tool

The grass wedge is mainly a mid–season grazing management tool (Macdonald et al., 2010). It is a snapshot in time of the amount of grass that is on a farm and its relationship to livestock demand in the form of a bar chart with each bar representing the pasture cover of an individual paddock in descending order. The demand line indicates the amount of feed required for a specific stocking rate, rotation length and livestock requirement. The grass wedge is generated from weekly pasture cover estimations and allows informed decision making around the implementation of grassland management strategies such as removing pasture surpluses when there is an excess, or reducing demand by introducing supplementation when pasture is in deficit.

The grass budget and the spring & autumn rotation planners (Macdonald et al., 2010) work simultaneously and aid in allocating the optimum quantity of pasture at these critical times in the grazing calendar when growth rates are typically lower than demand on dairy farms. This is of major importance as grassland management in the autumn will largely influence spring grass supply (O'Donovan and Dillon, 1999). The spring and autumn rotation planner's function through area based calculations which are determined by rotation lengths. The rotation planners specify the area of grassland that a farmer can afford to allocate to the livestock on a daily basis to maximize the amount of pasture in the diet over the time period of interest. The grass budget operates on a kg DM basis which is automatically populated through pasture cover estimations entered by the farmer. This allows daily allocations to be determined and pre-planned, incorporating pasture supply and demand predictions during a period of the farmer's choice.

2.3. Farmer inputs

Pasture cover estimations are entered on a weekly basis for the best use of the system. Estimations are taken by using either a platemeter (Jenquip, Fielding, New Zealand) (O'Donovan et al., 2002b) or by visual assessment (O'Donovan et al., 2002a). As the farmer enters the pasture cover estimations through the interface (Fig. 2), there are 5 different paddock status options available for selection. These are:

a. Grass – Area which is available for grazing
b. Being Grazed – Area which is currently occupied by livestock
c. Silage – Area which is earmarked for silage making
d. Reseed – Area which is under-going the reseeding process
e. Other Enterprise – Area which is being used for purposes outside of the main enterprise

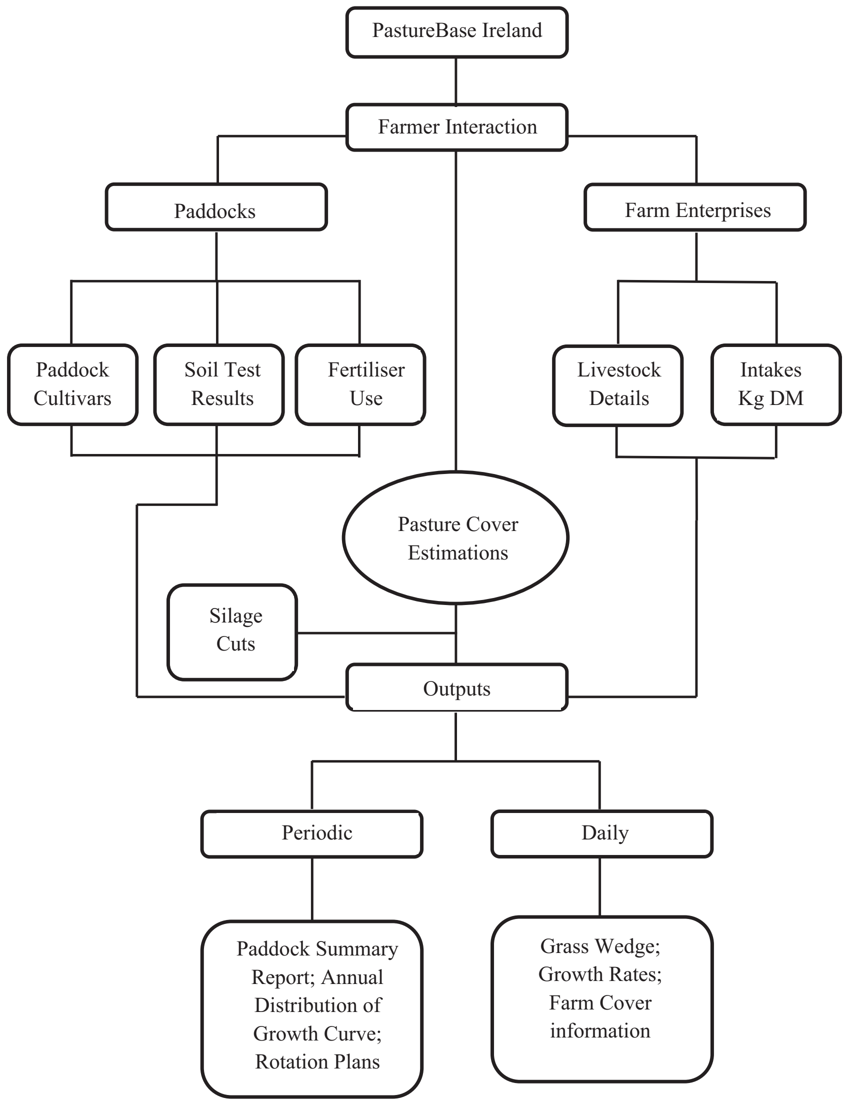

Fig. 1. Flow diagram of PastureBase Ireland system.

If a paddock cover reduces by greater than 200 kg DM/ha between two cover estimations the farmer is prompted to enter defoliation (grazing or silage event) details into the system. A graze or cut date and a residual are required for the paddocks in question. The farmer enters the date for each defoliation event for each paddock to allow for the correct historic growth rate calculations to be generated. This information is also required to calculate the average number of defoliations per paddock across the farm. A basic part of the interaction with the system is the weekly input of livestock details such as cow numbers and DM intakes to calculate daily farm demand, stocking rates and allocations per livestock unit. Reseeding dates, methods and cultivars are recorded along with soil tests as and when they occur.

2.4. Estimating growth

The PBI system functions through a series of calculations which uses the data entered by farmers to produce a number of pasture growth reports. The method used to calculate the growth rate of the paddock is determined by the paddock status (Grass, Being Grazed, Silage, Reseed, or Other Enterprise). The following pasture growth calculations are included in the system.

2.4.1. Daily growth rate – paddock

Daily pasture growth rates (kg DM/ha/day) are calculated for all paddocks that have a paddock status as ‘Grass’ and have a cover estimate that is greater than or equal to the previous pasture cover estimate.

$$\text{Growth rate} = \frac{\text{pasture cover estimate} - \text{previous pasture cover estimate}}{\text{days}} \tag{1}$$

(Days = cover date – previous cover date)

In the case where a platemeter is used as an estimation method, the growth rate is calculated by firstly converting the platemeter compressed sward height (CSH) (cm) to a pasture cover estimate (kg DM/ha) based on the following equation:

$$\text{Herbage} = (\text{sward height (cm)} - \text{residual height (cm)}) \times \text{sward density (kg DM/cm}^3) \tag{2}$$

Sward density = pasture cover mass; kg DM/ha/(pre-cutting – post cutting CSH); kg DM cm^3 (Delaby and Peyraud, 1998) (This parameter is set within PBI by the administrator)

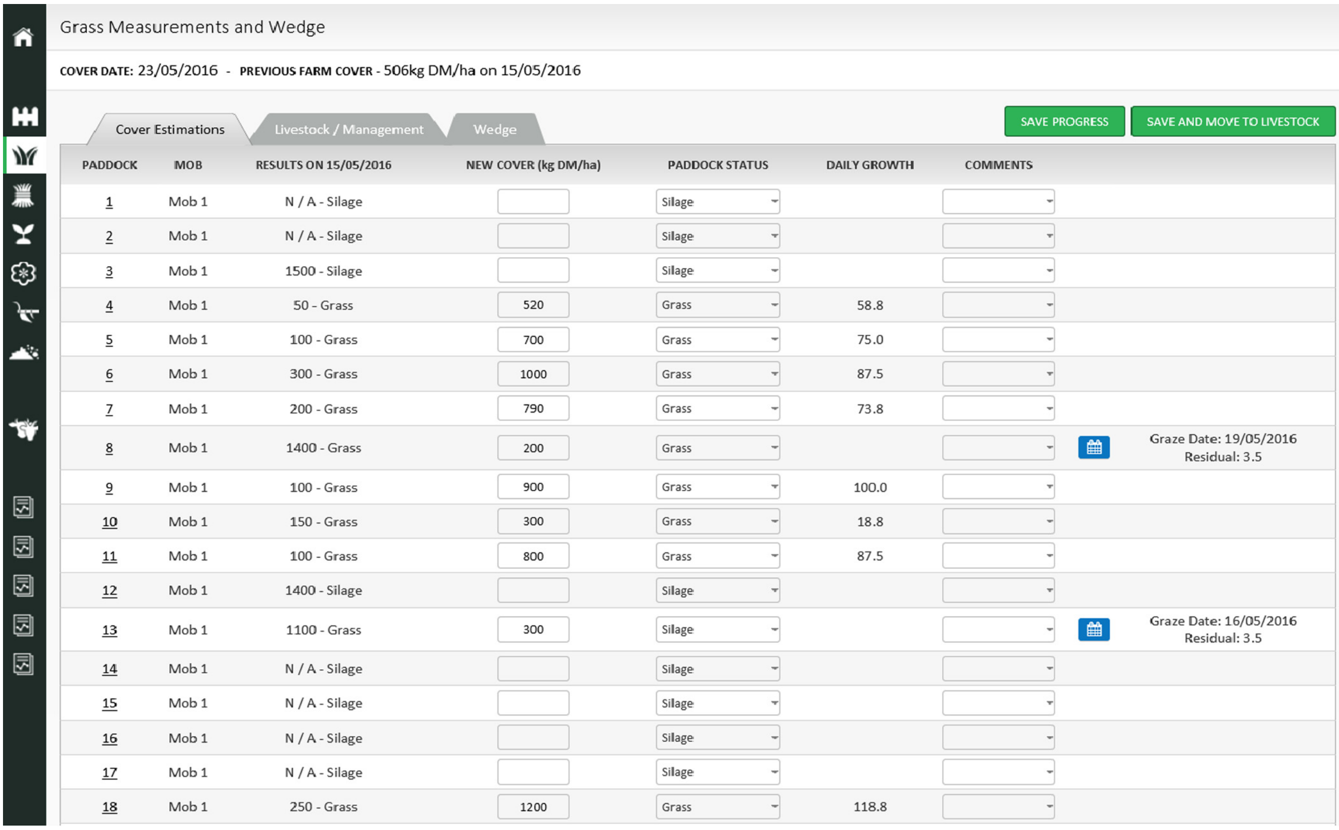

Fig. 2. Screenshot of PastureBase Ireland user interface for entry of pasture cover estimations.

If the paddock is grazed the defoliation option is 'grazed' and there is a 'graze date' required and prompted for the farmer, because the same calculation cannot be used for this growth, a different calculation is used. This is to account for growth between the previous cover date and the graze date and growth between the graze date and the subsequent cover estimation.

$$\text{Growth} = \frac{((\text{previous growth rate} \times \text{days pregrazing} + \text{cover estimate}) \pm \text{residual})}{\text{days}} \tag{3}$$

Previous growth rate = previous growth rate for that paddock from the previous cover estimation
Days pre-grazing = graze date − previous cover date
Cover estimate = next pasture cover estimation on cover date
Days = cover date − previous cover date
Residual (kg DM/ha) = (standard residual height (cm) − grazing residual (cm)) × sward density (kg DM/cm^3)
Standard residual height (cm) = 4 cm (O'Donovan et al., 2002b)
Grazing residual = residual entered by the farmer on recording of a defoliation event; if no value is entered the standard residual height is assumed to be valid

2.4.2. Daily growth rate – farm

A daily farm growth rate (kg DM/ha/day) is calculated using all paddocks that have a pasture cover estimate greater than the previous pasture cover estimate. Daily farm pasture growth is calculated as the difference in pasture cover estimates on all paddocks with a current paddock status of 'Grass' and the previous paddock status of 'Grass'. The daily growth rates are only calculated where there are two measurements within a defined period.

$$\text{Daily Farm Growth Rate} = \frac{\sum_i((\text{Paddock}_i \text{ growth rate}) \times \text{area}_i)}{\text{toatla area}^*} \tag{4}$$

i = All paddocks which have pasture growth of zero or greater with a pasture cover estimate greater than the previous pasture cover estimate (paddock 1, 2 …n)
Total area of all paddocks which have pasture growth of zero or greater with a pasture cover estimate greater than the previous pasture cover estimate

2.4.3. Cumulative pasture growth (Paddock & Farm)

Cumulative growth (kg DM/ha) is the sum of all the pasture grown in a defined period between two specific dates. This is measured at paddock and farm level on a per hectare basis.

a. 'Grass'

Cumulative DM yield of each paddock is calculated by the sum of all daily pasture growth rate figures for each paddock.

b. 'Being Grazed'

During a farm walk to complete a farm cover there will in general be one or more paddocks being grazed by livestock. When a paddock is classified as being grazed then it is difficult to get a reflective assessment of the pasture cover before being grazed. In that situation the previous week's growth rate is classified as the actual growth rate for that week as it is not possible to calculate a growth rate for the week in question for that paddock.

c. 'Silage'

When the silage paddock status is selected then no growth rate is calculated for this paddock during this period. This is an indication that the paddock is being removed from the grazing rotation for a period of time. When silage is harvested off a paddock, the farmer is prompted to change the paddock status from 'Silage' to 'Grass'. The farmer is then prompted to record a cut date, silage DM yield and a residual. This silage DM yield value is held as a record of silage production and used for calculating cumulative DM yields. Any growth rates which may have been previously calculated between the previous 'graze date' and the 'date cut' are removed to avoid double counting.

Pasture growth (kg DM/ha/day) is then calculated for the paddock regrowth from the cut date to the current cover estimate through the following equation;

$$\text{Growth rate} = \frac{(\text{cover estimate} \pm \text{residual})}{\text{days}} \tag{5}$$

Residual (kg DM/ha) = (standard residual height (cm) – grazing residual (cm)) × sward density (kg DM/cm^3)
Days = cover date – cut date (date paddock was cut for silage)

d. 'Reseed'

This paddock status is selected while the reseeding process is taking place and for as long as the paddock is out of the rotation. No growth rate is calculated when this option is selected. The system will resume calculating growth rates for the paddock when the 'Grass' option is selected which indicates the paddock has returned to the grazing rotation.

e. 'Other Enterprise'

No growth rate is calculated when this paddock status option is selected if no pasture cover estimate is taken otherwise the calculations from above apply.

2.5. System evaluation

The capacity of PBI was evaluated to estimate individual (pasture cover at any one defoliation event) and cumulative pasture DM yields from weekly entered pasture cover estimations. We evaluated the system by comparing specific PBI outputs with actual (Etesia) pasture cut information from 33 paddocks consisting of 252 defoliations across 2014 on the Moorepark research farm (Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland) (latitude 50°07 North, 8°16 West).

Farm pasture cover estimations were consistently completed on a weekly basis throughout the grazing season (consisting of 40 pasture cover estimations) using the visual assessment method of estimation of pasture cover (O'Donovan et al., 2002a) based on best practice within the Irish dairy industry. A team was used to take the pasture cover estimates to increase the accuracy of the estimations and to minimize errors through consultations. The pasture cover estimations recorded by the measurement team were continuously calibrated by comparing to cutting and weighing methods to ensure accuracy within and across recorders (O'Donovan et al., 2002a).

Pasture cuts for use in the comparisons with PBI outputs were taken every Monday and Thursday on the paddocks which were due to be grazed in that week. This practice was carried out for the full grazing season. These cuts were taken using an Etesia mower (Etesia UK Ltd., Warwick, UK). The paddock available pasture (>4 cm) was determined by harvesting two strips (1.2 × 10 m) of pasture on the closest date preceding the grazing of the paddock. All harvested pasture was then collected and weighed with a subsample (100 g) of this removed pasture taken for DM analysis. The DM percentage of the pasture was determined by drying this subsample in an oven for 16 h at 90 °C. This information collected through the Etesia cutting process was used to accurately calculate the DM yield of each paddock before each grazing event. This is seen to be the gold standard of field pasture cover measurement in the industry and has been used in previous studies (Creighton et al., 2012; Kennedy et al., 2006; McCarthy et al., 2013).

2.6. Statistical analysis

The accuracy of the PBI (computed) and Etesia (actual) comparison was evaluated by statistically analysis using the root mean square error (RMSE) (Bibby and Toutenburg, 1977), the relative prediction error (RPE) (Rook et al., 1990) and concordance correlation coefficients (CCC) (Lin, 1989) as used in previous studies (Baudracco et al., 2013; Delagarde et al., 2011; Ruelle et al., 2015). The RMSE was calculated using the Etesia cut data as the measure of actual data and PBI output as the predicted estimate. The RMSE provides information on the accuracy of the simulation by comparing term by term the actual and predicted data. The lower the RMSE suggests greater accuracy within the simulation. The RPE is calculated using the mean value of the Etesia outputs as the actual data. According to (Fuentes-Pila et al., 1996), an RPE lower than 10% indicates a satisfactory prediction, between 10% and 20% is a relatively acceptable prediction, and an RPE greater than 20% suggests a poor prediction. The CCC evaluates the correlation between two datasets but also the deviation from the 45° line. The CCC is composed of two components, the Pearson correlation coefficient and the bias correction factor. The Pearson correlation coefficient evaluates how far each observation deviated from the best-fit line whereas the bias evaluates the deviation from the 45° line (Bias = 1 if no deviation). The strength of agreement is considered poor if the CCC is lower than 0.65, moderate if between 0.65 and 0.80, substantial if between 0.80 and 0.90 and excellent if greater than 0.90 (McBride, 2005).

2.7. Evaluation comparisons

In the evaluation process we compared PBI outputs to corresponding Etesia cuts for

(1) DM yields of individual defoliation events for all 252 defoliations to determine the capability of the system to calculate pasture cover at each grazing or silage event (*Comparison 1*),
(2) Total DM yields of each paddock for the full grazing season including silage data (*Comparison 2*),
(3) Total DM yields of each paddock excluding silage data for the full grazing season (*Comparison 3*).

All comparisons were completed on a per hectare basis. The inclusion and exclusion of silage data was considered when calculating cumulative DM yields to gain a more in depth insight into the two measurements under an intensive grazing environment.

2.8. System application

The utility of the system was demonstrated by analyzing annual and seasonal DM yields of commercial farms across 2014 and 2015, with particular interest in the variation within and between farms. This analysis was completed using a sub sample of PBI users, containing 75 farms which on average had 34 paddocks each. Each farmer was required to have at least 30 pasture cover estimations completed in each year to ensure a high level of accuracy amongst the data. The information used was downloaded from the PBI database to Microsoft Excel to facilitate analysis of the data. The data was categorized by spring (1 Feb – 10 Apr), mid-season (11 Apr – 6 Aug), autumn (7 Aug – onwards) and total annual DM yield as defined by McEvoy et al. (2011). The DM yield mean and standard deviation were calculated at farm and paddock level across all 75 farms containing 2547 paddocks, for each year on an annual and seasonal basis. A *t*-test was then completed using the SAS 9.3 statistical analysis program to determine the significance of the differences in DM yield between 2014 and 2015.

3. Results

3.1. System evaluation

When PBI was compared to individual pasture cuts (*Comparison 1*) the RMSE for DM yields at each defoliation event was 409 kg DM/ha resulting in an RPE of >20%. The comparison also had a CCC of 0.91 and a bias of 1 (Table 1). Fig. 3 displays a regression analysis of the Etesia cuts and the PBI system; the association between methods had an R^2 of 0.84.

When PBI was compared on the cumulative DM yield (*Comparison 2*) the RMSE for DM yield per hectare was 2270 kg DM/ha resulting in an RPE of 15.4%. The comparison also had a CCC of 0.85 and a bias of 0.97 (Table 1). The association between PBI and cumulative Etesia yield resulted in an R^2 of 0.58 (Fig. 4).

When PBI was compared on the cumulative DM yield excluding silage cuts (*Comparison 3*) RMSE for DM yield per hectare was 2266 kg DM/ha resulting in an RPE of >20% when silage data was excluded. The comparison also had a CCC of 0.84 and a bias of 0.9 (Table 1). The association between PBI and cumulative Etesia yield excluding silage cuts resulted in an R^2 of 0.88 (see Fig. 5).

3.2. System demonstration

The analysis of commercial farm data demonstrates the variation in cumulative pasture growth across farms and across paddocks within farms for 2014 and 2015 (Table 2). The seasonal distribution in 2014 of pasture growth across the spring, mid-season and autumn periods were 8%, 52% and 40% respectively. There was a significant increase in total farm pasture growth in 2015 over 2014 (P 0.0434). On a seasonal basis the spring (P 0.0025) and autumn (P 0.003) increase were also significant but not for the mid-season growing period. The seasonal distribution of growth in 2015 across the spring, mid-season and autumn periods were 9%, 50% and 41% respectively.

4. Discussion

The advancement of decision support tools in agriculture centre on the complex nature of the decision making processes around key aspects of the farm from a strategic or tactical management perspective (Rogers et al., 2004). These decision support systems typically are integrated through computerized approaches to assist the user in problem solving or decision making (Newman et al., 2000). Effective decision support tools integrate information from a number of sources allowing for more informed decisions to be made, which can direct farmers towards more efficient production strategies. As outlined by Groves (1999) the increased use of technology at farm level can have significant economic and social ben-

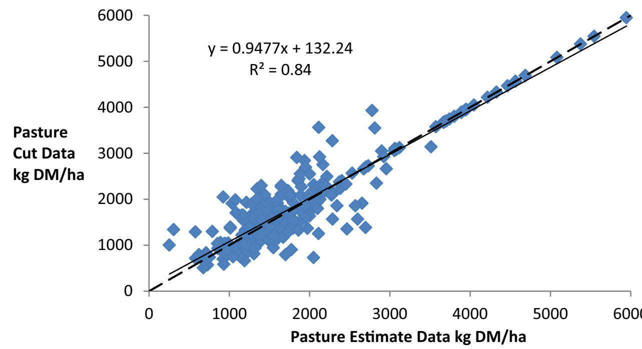

Fig. 3. Individual defoliation event measurements from PastureBase Ireland and pasture cut data (Etesia cuts) across the 2014 grazing season. Solid line is the regression line. Dashed line is the one-on-one line.

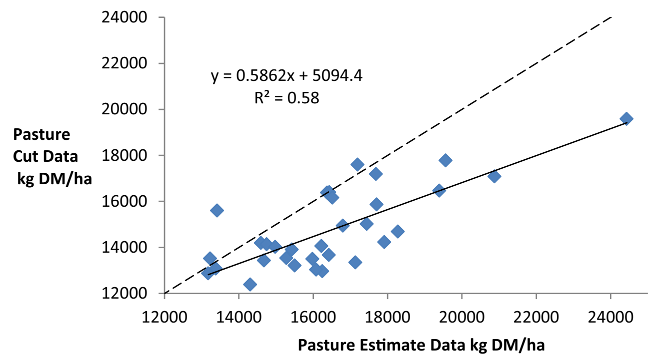

Fig. 4. Cumulative DM yield measurements from PastureBase Ireland and pasture cut data (Etesia cuts) for the 2014 grazing season including silage data. Solid line is the regression line. Dashed line is the one-on-one line.

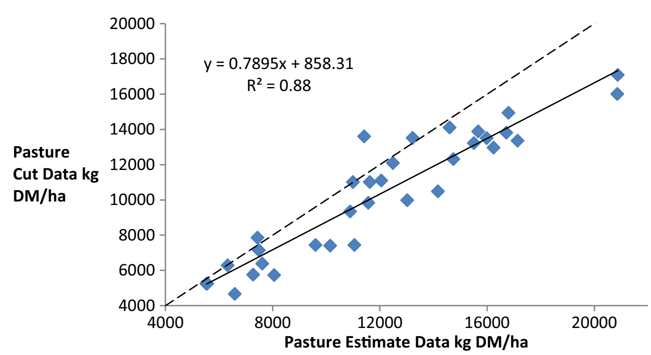

Fig. 5. Cumulative DM yield measurements from PastureBase Ireland and pasture cut data (Etesia cuts) for the 2014 grazing season excluding silage data. Solid line is the regression line. Dashed line is the one-on-one line.

Table 1
Statistical comparison of outputs from PastureBase Ireland and pasture cut data (Etesia cuts) for the 2014 grazing season.

	PBI mean (kg DM/ha)	Pasture cuts mean (kg DM/ha)	RMSE (kg DM/ha)	RPE (%)	CCC	Bias
Individual defoliation events	1886	1920	409	21.3	0.91	1
Cumulative yield including silage	16,412	14,715	2270	15.4	0.85	0.97
Cumulative yield excluding silage	12,102	10,414	2266	21.8	0.84	0.9

Table 2
Mean and standard deviation of PastureBase Ireland commercial farm data for the DM yield of 75 farms for 2014 and 2015 on an annual and seasonal basis.

		Spring (kg DM/ha)	Mid-season (kg DM/ha)	Autumn (kg DM/ha)	Total (kg DM/ha)
2014	Farm	843 (±380)	5478 (±1693)	4274 (±1066)	12,733 (±3026)
	Paddock	824 (±582)	5363 (±3201)	4190 (±1766)	12,452 (±4712)
2015	Farm	961 (±317)	5588 (±1388)	4567 (±1188)	13,197 (±2753)
	Paddock	943 (±557)	5460 (±3006)	4492 (±1858)	12,928 (±4721)

efits through the rate and volume of information exchange in particular through the use of the internet and smart phones.

PBI provides instant collection and storage of live data with outputs that are produced in real time, as well as having centralized data storage mechanisms. This allows for the direct connection with different groups and organizations including advisors and researchers aiding in the development of new technologies and research innovations. PBI encourages farmers to interact with decision support tools resulting in a win: win situation as the grassland farmer uses the tool to assist in making better decisions while the data is collated in a centralized database. Issues at farm level also will be viewed much faster due to the direct link with the administrators, advisors and researchers using the system together, creating a step change in the integration of research with farmers, and ultimately bringing the use of citizen science into real time grassland research. Citizen science has proved highly successful in the past in many countries, forming the bedrock of biological recording in various large research projects particularly in ecology and environmental sciences (Silvertown, 2009). In the case of PBI the farmers are the citizen scientists collecting the grassland data which can fuel a whole new research program. Already, PBI has led to the creation of discussion forums that support new research and technology initiatives through increased engagement with farmers. Discussion groups can be created by county, region, soil type, grass cultivars, etc., which can allow for a more targeted approach to benchmarking within and between farms facilitating citizen science (Silvertown, 2009).

4.1. Estimation methods

The measurement of pasture cover and its link to pasture DM production has been included in numerous previous studies (Creighton et al., 2012, 2011; García and Holmes, 2005; Kennedy et al., 2006; McCarthy et al., 2013; O'Donovan et al., 2002a,b). These previous studies strongly recommend the wide spread use of pasture measurement and budgeting at farm level; reporting increases in pasture production and utilization through higher levels of grassland management. The method of pasture cover estimation used in this study was visual assessment (O'Donovan et al., 2002a) with the operators being continuously calibrated with the cutting and weighing method using the quadrat and shears (O'Donovan, 2000). In a study carried out by O'Donovan et al. (2002b) it was reported that the visual assessment method with regular calibrated assessments was the most accurate method of pasture cover estimation when compared across operators, with the rising plate meter, sward stick and the pasture probe capacitance meter. In a separate study the visual assessment method accounted for 90% of the variation in DM yield with a mean standard deviation for the pooled seasonal error of 265 kg DM/ha when compared to Agria (Pasture cutting machine; Agria-Werke, Moeckmuehl, Germany) pasture cut measurements (O'Donovan et al., 2002a). In conclusion, the visual assessment method of cover estimation can be used accurately provided the observers are continually calibrated using the cut and weigh method of measurement (O'Donovan et al., 2002a).

4.2. System evaluation

This study focuses on the evaluation of the PBI system and how accurately the calculations within the system function, as pasture cover estimation methods have previously been validated (O'Donovan et al., 2002a,b). The PBI system has a relatively high level of accuracy considering the comparison involved has three potential sources of error (visual estimation errors, Etesia cut errors and methodology errors), in particular as they are in general field measurements taken in-situ. Therefore, users must consider the potential implications of errors in pasture cover estimates when determining stocking strategies and feed budgets. The use of experimental data in order to evaluate outputs from models is common practice. Previous research conducted by Hurtado-Uria (2013) developed a simulated grass growth model and compared it to another predictive model (Jouven model) (Jouven et al., 2006a,b). In the evaluation process Hurtado-Uria (2013) compared the model to actual pasture cut data. The results of our analysis showed a high correlation between PBI outputs and pasture cut data but also a high relative prediction error threshold (Table 1). This positive correlation shows PBI can estimate accurate DM yields under an intensive grazing environment, which is one of the core system objectives. The lower level of agreement in *Comparison 2* ($R^2 = 0.58$) is likely to be caused by the narrow range in data that results when silage data is included as there is a narrow range in the annual DM yield of all paddocks, as opposed to when silage data is excluded (*Comparison* 3), but conversely has a more favorable prediction error (RPE of 15.4%).

4.3. System application

The demonstration of PBI shows the variation in annual and seasonal DM yield on farm. Increasing the knowledge around the reasons for seasonal and annual differences within and across farms will help reduce variation through determining the most suitable corrective measures e.g. reseeding, soil fertility, etc. The utility of the PBI system is also observed under this evaluation process for its ability to act as a centralized database for research data. The results indicate a significant increase in pasture DM yield across farms from 2014 to 2015 (P 0.0434) and also at paddock level (P 0.0407). This increase is most likely due to year and weather effects, with further investigation required over a longer time period to determine if the use of PBI can be attributed to increases in DM yield at farm level. This type of data over time will allow analysis to be completed, identifying the main factors affecting these changes in pasture growth. The results show variations between farms (Table 2) in 2014 and 2015 which is to be expected due to varying meteorological conditions, region, soil type and varying levels of management. However the results display greater variation across paddocks within farms with an annual higher standard deviation (Table 2) in 2014 and 2015 which would suggest there is potential to increase growth across paddocks within farm. The reasons for this underperformance must be explored with it more likely to be caused by suboptimal soil nutrient status, poor grass cultivars or inadequate grazing management in those particular paddocks. The use of PBI allows underperforming paddocks to be identified and targeted action to be taken at farm level.

4.4. Decision support system

Farmer interaction is fundamental to the success of PBI and for the full benefit of the decision support system to be realized. The four main features of the system the farmer interacts with for instant application are the grass wedge, grass budget and the spring & autumn rotation planners (Macdonald et al., 2010). The use of these specific tools is not restricted to Ireland and are already widely recognized and used internationally by New Zealand and Australia for the benefits they provide in terms of decision support (Macdonald et al., 2010). The correct use of these tools have major advantages in terms of managing pasture supply, quality and utilization (Creighton et al., 2011). The implementation of PBI can have a majorly positive effect on farm physical and financial performance with previous studies clearly illustrating the advantages of improved grassland management performances on commercial farms and how this has the potential to increase profits (Shalloo et al., 2011). Information derived from PBI will help farmers to more easily determine the production capacity of their farm, while determining the most suitable stocking rates for the farm's pasture growth capabilities. This is of major importance as determining the correct stocking rates for pasture based milk production on individual dairy farms has implications on dairy farm production and profitability (Kennedy et al., 2007; MacDonald and Penno, 1998).

Previous research has shown that technology adoption can be limited at farm level (Creighton et al., 2011), however it has been shown that the use of benchmarking and on farm trials investigating new practices have the effect of strengthening the relevance and acceptance of research (Rhoades and Booth, 1982). These findings reinforce the requirement for more interactive dissemination of research at farm level through the use of tools such as PBI. This offers farmers a direct link to the latest grassland developments, which could potentially include the posting of research updates and technical bulletins on its web front end or interaction with the latest pasture cover estimation technologies. The accessibility of such information and knowledge has become increasingly easier through the advancement of internet technologies creating a stronger channel of communication between research, advisory and farmers.

4.5. Central database

PBI has the potential to refocus grassland research through the benefits that will come from the large quantities of on farm information collected in the centralized database. As the database develops this will allow for further evaluation of DM yields at the paddock level which will ultimately facilitate the evaluation of different characteristics of the paddock whether its cultivar, soil fertility, etc. This interlinked research which PBI can provide will generate vital information for the further development of an economic ranking index for perennial ryegrass cultivars (McEvoy et al., 2011; O'Donovan et al., 2016). This data will provide direction to the grassland industry in terms of grass breeding for the most desirable production traits to deliver the most profitable grassland swards for milk and meat production.

5. Conclusion

The study has demonstrated the potential of the newly developed PBI system to provide decision support for farmers while collating large quantities of grassland data. Appropriate pasture measurement and budgeting is the key driver of farm potential in terms of pasture growth and utilization (Creighton et al., 2011). For farmers the initial direct impact of PBI will come from the advancement of the decision making process through regular pasture measuring and budgeting on farm. These management practices will allow farmers to enhance their grazing management skills through grazing pasture at the right stage ultimately increasing intake and quality. This allows farmers to more easily evaluate paddocks and cultivars on farm which will instill a greater sense of control over grassland production and therefore increase DM yields and promote superior pasture feeding regimes. The centralized database which PBI supports will contain a wealth of knowledge to facilitate future grassland research programs and developing new methods of grassland evaluation. In essence, contributing to substantial increases in both productivity and profitability on pasture based farms.

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